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Performance Analysis of Absorption Refrigeration Cycles

B. Anusha[1], B. Chaitanya[2]

[1]Department of Mechanical , Gudlavalleru Engineering College/JNTU K, India
[2]Department of Mechanical, V R Siddhartha Engineering College/JNTU K, India

Abstract— *The thermodynamic analysis of a vapor absorption refrigeration system employing ammonia as the refrigerant are presented. The thermodynamic analysis of these three combination of the absorption pairs namely NH_3/H_2O, $NH_3/LiNO_3$, $NH_3/NaSCN$ are performed. The best alternative to the ammonia water absorption pair are proposed as ammonia lithium nitrate and ammonia- sodium thiocyanate. It is very much important to select a prominent working substance and their properties have great effect on the system performance. Detailed thermodynamic properties of these fluids are expressed in polynomial equations. Energy and entropy balance equations are applied to analyse each of the process to estimate the individual heat transfer and entropy generation rates for all the systems. Among these three pairs NH3/ NaSCN yields the highest coefficient of performance. Cooling/Heating of the generator/absorber results in significant entropy generation in all the systems. The solution heat exchanger significantly improves the performance of the cycle and yields in the better cooling output.*

Keywords— ***absorption, refrigerant, evaporator, vaporizes, high temperature.***

I. INTRODUCTION

In recent years, growing energy needs, cooling load demand in industrial, commercial, domestic sectors, scarcity of fossil fuels, rise in fuel price and faulty power supply have made people contemplate greater use of renewable energy sources. Apart from this, use of refrigerants with high global warming potential, CO_2 emissions from the combustion of fossil fuels in the power generation lead to effects detrimental to the environment. In such cases, alternative sustainable technologies are desirable to attain a holistic environmental safety.

Absorption refrigeration systems are environment friendly as they use low grade nts, industrial plants and automobile emissions, and the low global warming potential. Although huge efforts have been spared over several past decades in this field, COP of the sorption refrigeration system is still quite low compared to vapor compression refrigeration systems; thus there is an urgent need for further improvements in material, component and overall system design to make these systems a viable alternative to vapor compression systems.

Absorption refrigeration system uses various refrigerant-absorbent combinations known as the solution pairs, it is important to select the appropriate working substance the properties of which have a great effect on the performance of the cycles. The absorbent acts as a secondary fluid to absorb the primary fluid which is the refrigerant in its vapor phase. The most widely used working fluid pairs in absorption refrigeration system have been ammonia-water and water-lithium bromide solutions.

Table.1: Working pairs for refrigeration applications

Liquid-gas (Absorption/ Chemical reaction)	**Solid-gas (Absorption/ Chemical reaction)**	**Adsorption**
$CH_3NH_2/H_2O/LiBr$	$H_2O/LiCl$	$C_2H_5OH/PX21$
$CH_3NH_2/LiSCN$	H_2O/NaI	$C_3H_8/PX21$
$CH_3OH/LiBr$	H_2O/K_2CO_3	$CH_3NH_2/PX21$
$CH_3OH/LiBr/ H_2O$	H_2O/Na_2S	$NH_3/PX21$
H_2O/ H_2SO_4	$H_2O/MgCl_2$	$SO_2/PX21$
$H_2O/LiBr$	$H_2O/CaCl_2$	H_2O/Silica gel
$H_2O/NaOH$	$H_2O/CaSO_4$	$C_2H_5OH/TA90$
NH_3/H_2O	H_2O/LiB	$CH_3NH_2/TA90$

Assumptions used in the simulation

1. Simulations and analyses are performed under steady conditions.
2. Conditions of the refrigerant (ammonia) at the exits of the condenser and the evaporator are saturated.
3. The solution is at equilibrium conditions at the exits of the absorber and the generator and at the corresponding device temperatures
4. Pressure losses due to friction in the heat exchangers and the connecting piping are negligible.
5. Heat exchanges between the systems and the surroundings, other than that prescribed by heat transfer at the generator, evaporator, condenser and absorber, are assumed negligible.

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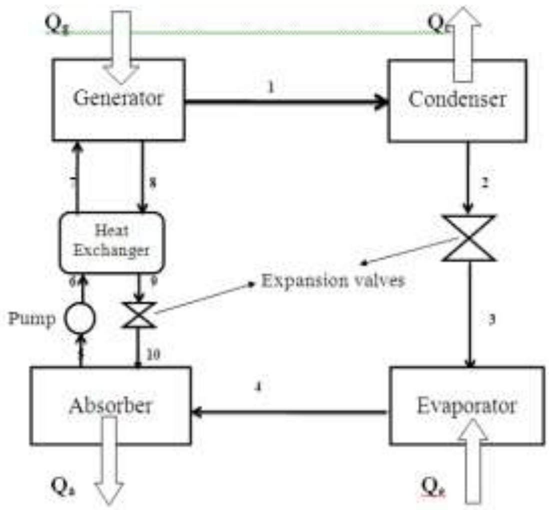
6. Simulations and analyses are carried out for a constant refrigeration capacity in all the systems.
7. The reference environment state for the system is the average temperature of the heat rejection media and 100 K Pa.
8. Salt properties such as density and specific heat are constant.

II. WORKING PRINCIPLE

The essential components of the vapor absorption system are an evaporator, an absorber, a generator, a condenser, a expansion valve, a pump, a solution heat exchanger. The compressor in the vapor compression system is replaced with an absorber, generator, pump, solution heat exchanger. Heat flows in the system at generator and it is directly added from the heat source like fuel burner, steam and work input takes place at pump for increasing the pressure and temperature what exactly compressor does in the vapor compression system. Heat rejection takes place at the absorber. The solution commonly used is aqua- ammonia.

Figure 1 shows the layout of the single effect absorption refrigeration system. The single effect cycle works between the two pressure levels, where higher pressure is at generator and condenser and the lower pressure is at absorber and evaporator. In this cycle the refrigerant used is the ammonia. High pressure liquid refrigerant 2 from the condenser passes into the evaporator 4 through an expansion value 3 that reduces the pressure of the refrigerant to the low pressure in the evaporator. The liquid refrigerant vaporizes in the evaporator by absorbing latent heat from the material being cooled and the resulting low pressure vapor 4 passes to the absorber, where it is absorbed by the strong solution 8 coming from the generator through an expansion value 10 and forms the weak solution 5. The weak solution exists in the absorber and its pressure is raised to the generator pressure by means of the pump 6 and this solution is pre heated by the solution heat exchanger 7 using the heat released by the strong solution 8 from the generator. The solution heat exchanger increases the cycle efficiency by avoiding the need to add that heat in the generator. In the generator a high temperature heat source is required to generate refrigerant vapor 1 from the weak solution. This refrigerant vapor 1 flows through the circuit and first becomes a liquid in the condenser and rejects heat to the cooling medium and the cycle repeats. The definition by ASHRAE to the weak/strong solution is that the ability of the solution to absorb the refrigerant vapor is weak/strong. If this cycle works on the ammonia water absorption pair then this had a added advantage of using the rectifier and analyzer to remove water vapor from the refrigerant mixture leaving the generator before reaching the condenser.



FIRST LAW OF THERMODYNAMICS

For the generator mass and energy balance is given

$m_7 = m_1 + m_8$ (total mass balance) …..1

$m_7 X_7 = m_1 + m_8 X_8$ (NH3 balance) ….2

$Q_g = m_1 h_1 + m_8 h_8 - m_7 h_7$

The flow rates of the strong and weak solutions are determined from the equations (1) and (12)

$$m_8 = \frac{1 - X_7}{X_7 - X_8} m_1$$

$$m_7 = \frac{1 - X_8}{X_7 - X_8} m_1 \quad \text{……….(3)}$$

The circulation ratio of the system is derived from the equation (3) as

$$f = \frac{m_7}{m_1}$$

The energy balance for the solution heat exchanger is as follows

$$T_9 = E_{ex} T_6 + (1 - E_{ex}) T_8$$

$$h_7 = h_6 + \frac{m_8}{m_6}(h_8 - h_9)$$

The increase in energy by using pumping is

$$h_6 = h_5 + (P_6 - P_5) v_6$$

$$W_{me} = (P_6 - P_5) v_6$$

The energy balance for the absorber is given by

$$Q_a = m_4 h_4 + m_{10} h_{10} - m_5 h_5$$

The energy balance for the condenser is given by

$$Q_c = m_1 (h_1 - h_2)$$

The energy balance for the evaporator is given by

$$Q_e = m_1 (h_4 - h_3)$$

The first law of thermodynamics for the basic cycle is given by

$$Q_g + Q_a + Q_c + Q_e = 0$$

The ideal COP is given by

$$COP_{ideal} = \frac{(T_g - T_a)T_c}{T_g(T_a - T_c)}$$

III. RESULTS AND DISCUSSION

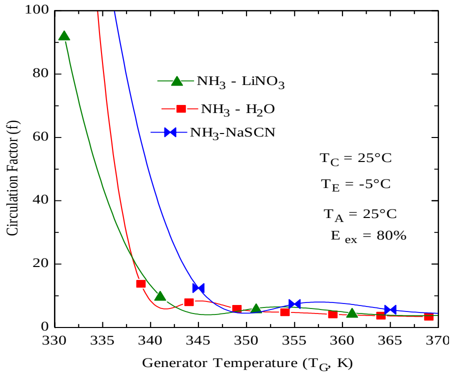


Fig. 2: Effect of COP on generator temperature

With the increase in the generator temperature the COP values also increases. By these comparision $NH_3/NaSCN$ has the best performance where the generature is at its temperature in higher limit. The $NH_3/LiNO_3$ gives the best performance at its lower generator temperature that is by using the solar energy etc. NH_3/H_2O has the lowest performance.

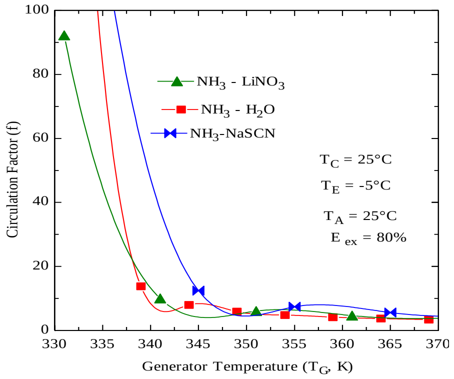


Fig. 3: Effect of circulation ratio with generator temperature

Comparison of the circulation factor values with the generator temperatures. The circulation ratio for the $NH_3/NaSCN$ cycle is higher than that of the other two cycles. This is that either the solution pump needs to run faster or a bigger pump is required. If the generator temperature reaches its low temperature limit then circulation factor increases tremendously, but it is highly impossible to operate a cycle at low temperature.

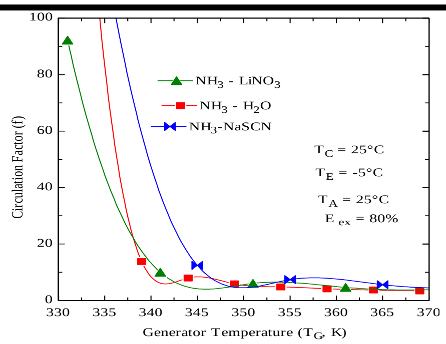


Fig. 4: Effect of COP on evaporator temperature

Comparison of the circulation factor values with the generator temperatures. The circulation ratio for the $NH_3/NaSCN$ cycle is higher than that of the other two cycles. This is that either the solution pump needs to run faster or a bigger pump is required. If the generator temperature reaches its low temperature limit then circulation factor increases tremondeously, but it is highly impossible to operate a cycle at low temperature.

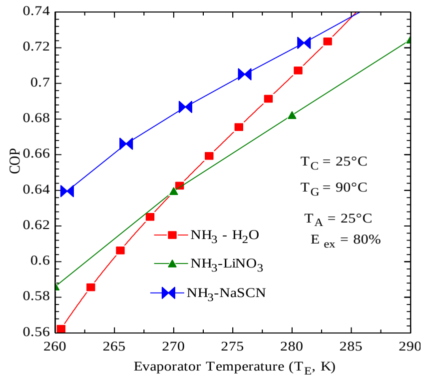


Fig . 5: Effect of circulation factor with Evaporator temperature

Comparision of the COP values with the evaporator temperature for the three absorption pairs. With the increase in the evaporator values the COP values also increases. But for the evaporator temperature lower than zero temperature range for the refrigeration the $NH_3/NaSCN$ gives the better performance and the ammonia/water cycle has lower COP values. However for the high evaporator temperatures the performance of the ammonia/water pairs gives better than $NH_3/LiNO_3$.

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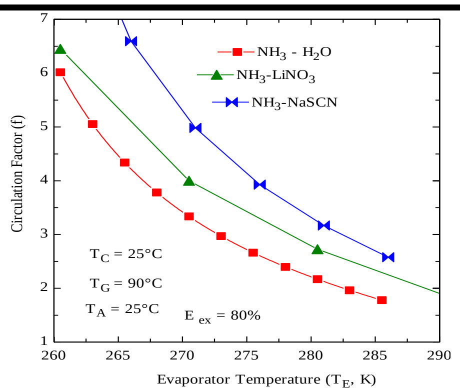

Fig. 6: Effect of COP on condenser temperature

The comparison of the circulation factor with evaporator temperature over the three absorption pairs. But the circulation factor for the NH_3/NaSCN cycle has best performance and is higher than the other two cycles.

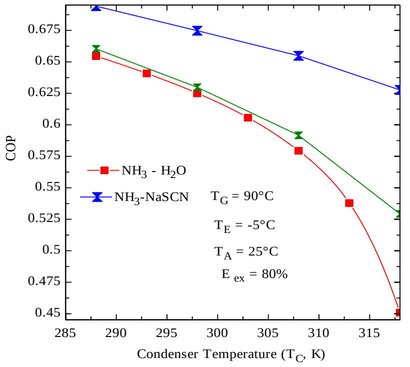

Fig. 7: Effect of circulation factor with condenser temperature

Comparison of the COP values with the change in the condenser values for all the three absorption pairs. By the increasing in the condenser temperature results in the decrease in the COP values. For the lower condenser temperature the absorption pair NH_3/NaSCN pair has better performance and for higher condenser temperatures the absorption pair NH_3/$LiNO_3$ has the better performance.

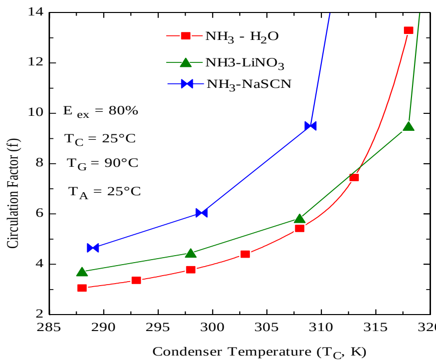

Fig. 8: Effect of COP with Absorber temperature

Comparison of the circulation factor with the condenser temperature for all the three absorption pairs. By the increase in the condenser temperature the circulation factor values also increases. And among all these the absorption pair ammonia/sodium thiocyanate has the better performance.

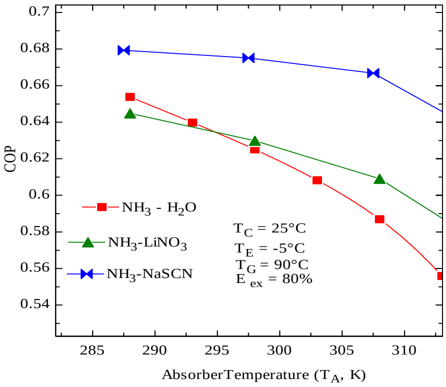

Fig. 9 : Effect of circulation factor with Absorber Temperature

Comparison of the effect of COP values with the absorber temperature for all the three absorption pairs. The effect of the absorber temperature is as similar to the condenser temperature values. As our assumptions both the condenser and the absorber should be at the same level. As on the absorber temperature increases there is a decrease in the COP values.

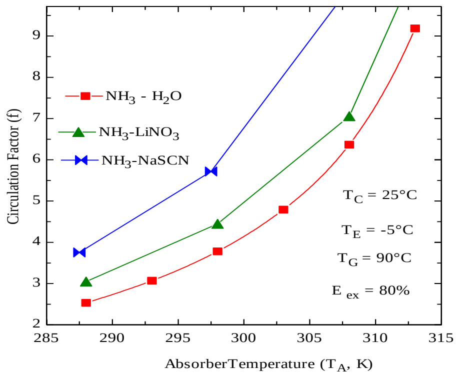

Fig. 10: Effect of external entropy with Generator temperature

Comparison of the circulation factor with the increase in the absorber temperature for all the three absorption pairs. The effect of the absorber temperature is as similar to the condenser temperature as they are working at the same temperature levels. As on the absorber temperature increases there is a increase in the circulation factor. Among these three absorption pairs the NH_3/NaSCN has the higher value than the remaining two absorption pairs, next to that NH_3/$LiNO_3$.

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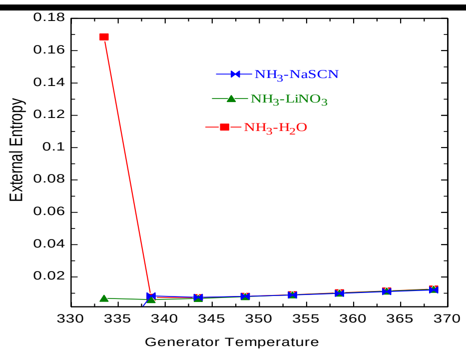

Fig. 11: Effect of Internal Entropy with Generator temperature

Comparison of the effect of the external entropy with the generator temperature for all the three absorption pairs. By the increase in the generator temperature the external entropy slightly increases for the two cases that is ammonia/sodium- thiocyanate and ammonia/lithium nitrate. For the absorption pair ammonia/water first at the initial condition it increases tremendously and then falls suddenly to a lower value and slightly increases. This external entropy is due to the heat transfer between the heat source and the generator

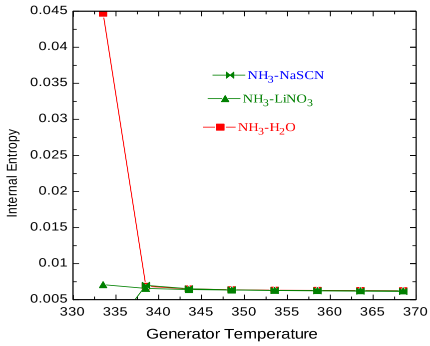

Fig .12: Effect of Total Entropy with Generator Temperature

For the absorption pair ammonia/water first at the initial condition it increases tremendously and then falls suddenly to a lower value and slightly increases. By the increase in the generator temperature the internal entropy slightly increases for the two cases that is ammonia/NaSCN and ammonia/lithium nitrate.

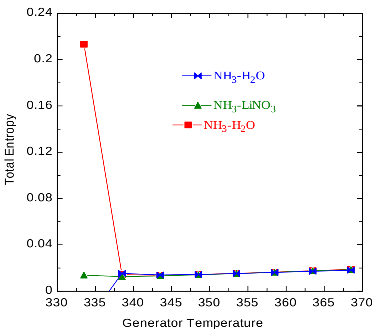

Fig .12: Effect of Total Entropy with Generator Temperature

Comparison of the effect of the total entropy with the generator temperature for all the three absorption pairs.For the absorption pair ammonia/water first at the initial condition it increases tremendously and then falls suddenly to a lower value and slightly increases. By the increase in the generator temperature the total entropy slightly increases for the two cases that is ammonia/ NaSCN and ammonia/lithium nitrate. Here total entropy is by the sum of internal and external entropy.

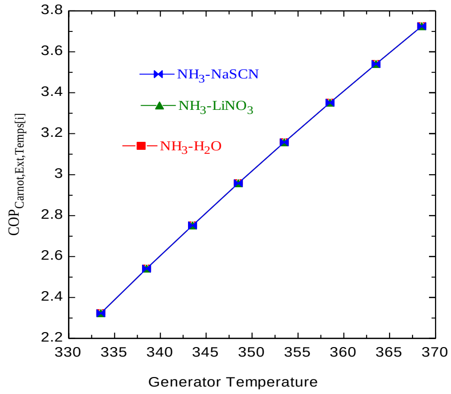

Fig.13 : Effect of carnot COP with Generator Temperature

Comparison of the Carnot COP to the generator temperature is given for the three absorption pairs. As the generator temperature increases the Carnot COP also increases similarly for all the three. Here Carnot COP is considered as the base line COP and compared with them.

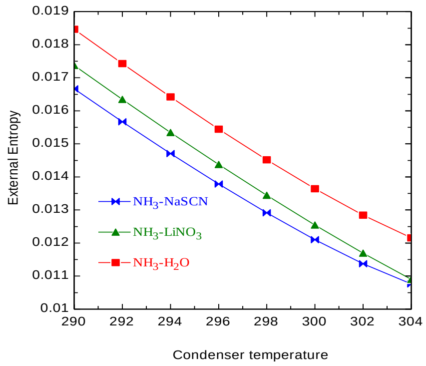

Fig .14: Effect of External Entropy with condenser temperature

Comparison of the effect of external entropy with the condenser temperature for all the three pairs that are used for the absorption. Here as the condenser temperature increases the external entropy decreases for all the three pairs. Among them the absorption pair ammonia/water has the highest entropy generation, next to that ammonia/$LiNO_3$ has the highest external entropy. The lowest entropy generation is for the ammonia/NaSCN absorption pair.

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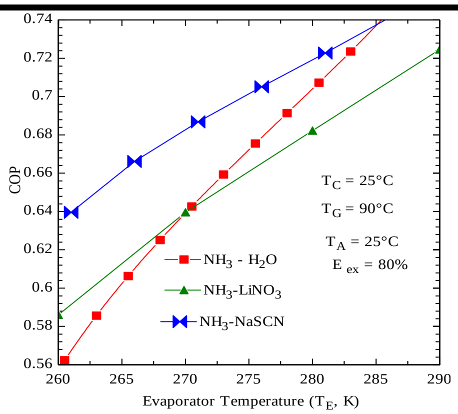

Fig . 15: Effect of Internal entropy with condenser temperature

Comparison of the effect of internal entropy with the condenser temperature for all the three pairs that are used for the absorption. Here as the condenser temperature increases the internal entropy also increases for all the three pairs. Among them the absorption pair ammonia/water has the highest internal entropy generated, and next to that ammonia/$LiNO_3$ has the highest internal entropy. The lowest internal entropy generation is for the ammonia/NaSCN absorption pair.

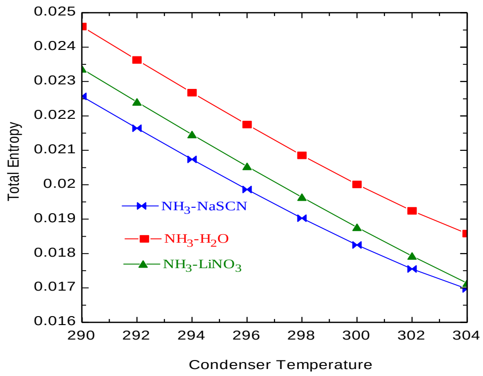

Fig. 16 : Effect of total entropy with Condenser temperature

Comparison of the effect of external entropy with the condenser temperature for all the three pairs that are used for the absorption. Here as the condenser temperature increases the total entropy decreases for all the three pairs. Among them the absorption pair ammonia/H_2O has the highest total entropy generated and next to that ammonia/$LiNO_3$ has the highest total entropy. The lowest total entropy generation is for the ammonia/NaSCN absorption pair. Total entropy is obtained from the both internal and external entropy.

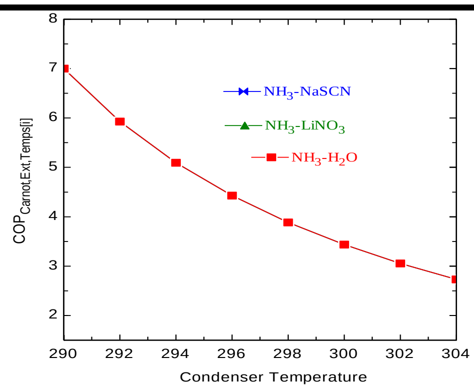

Fig.17: Effect of Carnot COP with Condenser temperature

Comparison of the Carnot COP to the condenser temperature is given for all the three absorption pairs. As the condenser temperature increases the Carnot COP decreases similarly for all the three absorption pairs. Here Carnot COP is considered as the base line COP and compared with these three absorption pairs and the COP that is obtained from the first and second laws is compared**.**

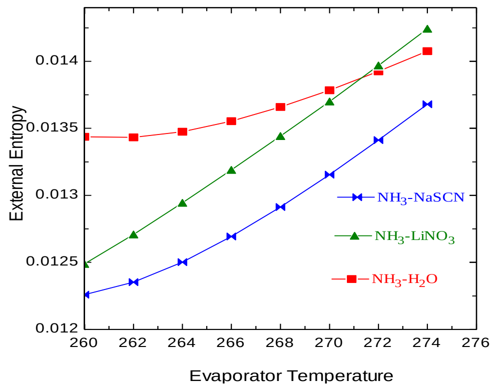

Fig.18: Effect of the External entropy with evaporator temperature

The effect of the external entropy with the evaporator temperature for all the three absorption pairs are compared. As the evaporator temperature increases the external entropy also increases. Among all these absorption pairs NH_3/H_2O has the highest entropy but as the evaporator temperature is increasing there is a sudden increase in the ammonia/$LiNO_3$ at the end and increases than NH_3/H_2O pair. The lowest entropy is for the ammonia/NaSCN pair.

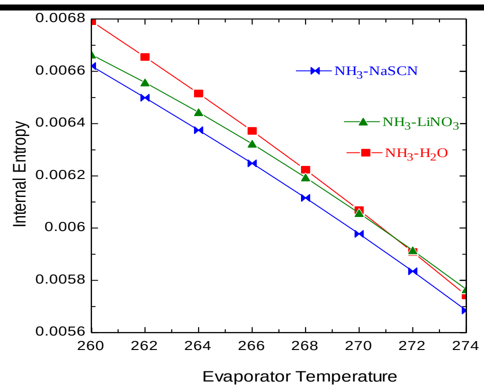

Fig.19: Effect of internal Entropy with evaporator Temperature

As the evaporator temperature increases the internal entropy also decreases. Among all these absorption pairs NH_3/H_2O has the highest entropy but as the evaporator temperature is increasing there is a sudden increase in the ammonia/$LiNO_3$ at the end and increases than NH_3/H_2Opair.

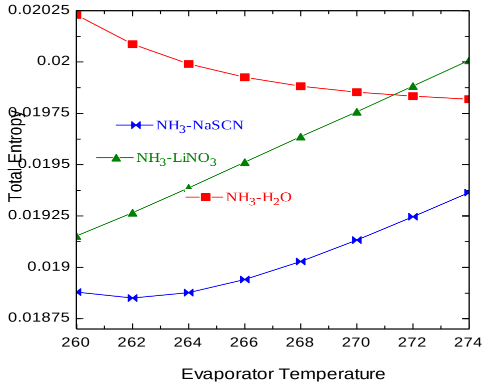

Fig. 20: Effect of the Total Entropy with Evaporator Temperature

The total entropy for the ammonia/water first increases and then decreases slightly. For the ammonia/lithium nitrate it increases and has the highest value as on the evaporator temperature increases. As usual the entropy is lowest for ammonia/sodium thiocyanate absorption pair.

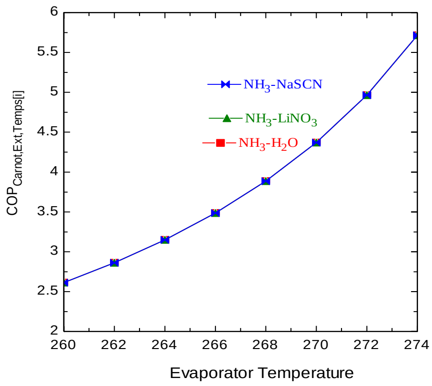

Fig. 21: Effect of the Carnot COP with the Evaporator Temperature

Comparison of the Carnot COP to the evaporator temperature is given for the three absorption pairs. As the evaporator temperature increases the Carnot COP also increases dramatically for all the absorption pairs. Here Carnot COP is considered as the base line COP and compared with the first and second law COP.

IV. CONCLUSIONS

1. Results for all the three combinations of the absorption pairs such as ammonia/water, ammonia/lithium nitrate and ammonia/sodium thiocyanate are compared.
2. The ammonia-water absorption pair is mainly used for the refrigeration temperatures below 0^0c.
3. The thermodynamic properties of these absorption pairs are expressed in polynomial equations.
4. The performances against various generator, absorber, condenser and evaporator are compared for all the three absorption pairs.
5. The result shows that the ammonia/NaSCN and ammonia/$LiNO_3$ gives the better performance than the ammonia/H_2O pair.
6. The absorption pairs have the better performance not only because of the higher COP but also because of the no requirement of analyzers and rectifiers.
7. Ammonia/NaSCN cycle cannot operate at the evaporator temperature below -10^0c for the possibility of crystallization.
8. But generally speaking ammonia/ sodium thiocyanate and ammonia/ lithium-nitrate have similar performance but operate at higher and lower temperature limits.
9. The first law and second law analysis are carried out and the COP's are compared.
10. Energy and entropy balance equations are applied to analyze each of the process to estimate the individual heat transfer and entropy generation rates for all the systems.
11. The entropy generated is higher for the ammonia/water pair and least for the ammonia/sodium thiocyanate pair.

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